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Data from blood flow studies suggest that visual priming involves automatic activation of a set of posterior visual areas that are not activated by auditory language processing. In accord with this account, we found no reduction in visual priming during simultaneous shadowing.

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Blood flow data indicate that semantic priming involves both an anterior attention system and an area of lateral frontal cortex. Both these areas can also be activated by auditory information. Our results suggest that semantic priming is greatly influenced by strategic factors that do not affect visual priming and is often reduced by auditory shadowing. The interaction of semantic priming with auditory shadowing depends little on the semantic character of the shadowing task (text versus nonsense) and thus appears to be large attentional.

We argue that a combined anatomical-cognitive approach provides a means for disambiguating the conditions under which interference between cognitive operations is likely to occur.

Is Word Recognition automatic?

A cognitive-anatomical approach[1]

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Abstract

It is generally accepted that two tasks will interfere to the extent that they require attention or involve shared non-attentional processing systems. We used anatomical data from studies of blood flow during lexical processing (Petersen, Fox, Posner, Mintun & Raichle, 1988) to generate hypotheses about the conditions under which an auditory shadowing task would interfere with three common visual priming tasks.

Data from blood flow studies suggest that visual priming involves automatic activation of a set of posterior visual areas that are not activated by auditory language processing. In accord with this account, we found no reduction in visual priming during simultaneous shadowing.

Cueing covert visual attention involves posterior parietal areas that are not involved in auditory shadowing. However, these posterior areas are part of a unified attention system. In accord with this idea, cueing covert attention is greatly affected by simultaneous auditory shadowing.

Blood flow data indicate that semantic priming involves both an anterior attention system and an area of lateral frontal cortex. Both these areas can be also be activated by auditory information. Our results suggest that semantic priming is greatly influenced by strategic factors that do not affect visual priming and is often reduced by auditory shadowing. The interaction of semantic priming with auditory shadowing depends little on the semantic character of the shadowing task (text versus nonsense) and thus appears to be largely attentional.

We argue that a combined anatomical-cognitive approach provides a means for disambiguating the conditions under which interference between cognitive operations is likely to occur.

There is a long history in experimental psychology of using simultaneous dual task performance to determine the extent to which two tasks share limited cognitive resources (Kinsbourne & Hicks, 1978; Posner, 1978; 1982). The logic underlying dual task paradigms is as follows: (1) tasks will interfere to the extent that they require attention and (2) tasks will interfere when their component operations are similar. The first criterion suggests that two poorly learned tasks will interfere irrespective of content. The second suggests that even highly overlearned tasks will interfere when their content is related.

Both of these criteria can be subsumed under a single anatomical proposition (Kinsbourne & Hicks, 1978). That is, tasks will interfere to the extent that their operations occur within a single or heavily interconnected anatomical system. If selective attention is performed by an integrated system, it is clear that tasks requiring this system will interfere. If processing of similar content is done in shared anatomical areas, one would also expect more interference when contents are related.

A major contribution of cognitive science has been the development of paradigms which allow for the study of isolated internal operations rather than entire tasks. One such paradigm uses an initial stimulus as a prime to improve one or more aspects of the processing of a second target stimulus. Since the subject does not have to respond to the first stimulus, such priming may serve to isolate those components that are shared between prime and target. Thus, if the word 'doctor' is a prime for the target 'nurse', it is thought to improve target processing by activating appropriate areas of semantic memory. If the word 'doctor' is a prime for the visually identical stimulus 'doctor', target processing could also be facilitated through shared visual, phonological and semantic activations. The mechanisms of priming are unresolved. One controversy concerns the extent to which priming effects are attentional or automatic (Neely, 1977). A more recent controversy involves the degree to which facilitation results from mediating search strategies instead of the activation of common representations (Ratcliff & McKoon, in press). Despite these difficulties we try to use priming as a tool for isolating particular operations. The results of these efforts can also be used to evaluate the assumptions on which they are based.

Advances in imaging technology have recently yielded evidence concerning the anatomical systems activated by visual words in healthy subjects (Petersen et al., 1988). These studies have relied upon changes in blood flow when performing a series of three common lexical tasks, each differing from the next by a single processing operation (e.g. passive word presentation followed by word repetition). The operations involved in the tasks are similar to those in a typical priming paradigm. The results of the study are summarized in Figure 1.

INSERT FIG. 1

We used this anatomical data to generate hypotheses about the conditions under which an auditory/verbal task requiring attention would interfere with three common visual priming tasks. The three tasks are visual priming of a word (e.g. doctor - doctor), semantic priming a word (e.g. nurse - doctor), and cueing of visual spatial attention (e.g. a cue to attend to the left of the screen followed by a target to the left for a valid trial or to the right for an invalid trial).

The anatomical basis of the shared activations between cue and target in these three tasks can be inferred from Fig. 1. For example, the area most likely to mediate priming of visual features is the ventral occipital lobe (see areas called visual word forms, Fig. 1). Petersen, Fox, Miezin & Raichle (1988) suggest that these areas form a network for the development of visual word forms from visual features. We hypothesize that word primes activate these areas and that an identical prime will reactivate the same pathway within the network. In the PET study activation of the ventral occipital lobe was very similar, irrespective of whether subjects responded actively or passively to the input word, indicating that the areas are not part of the attentional system.

The PET study suggests that semantic tasks activate two additional areas (see semantic and anterior attention areas, Fig. 1). One of these is unique to semantic processing of language stimuli, whether visual or auditory, and lies in the left inferior prefrontal cortex. The second is in the anterior cingulate and appears related to the person's attention to the word. We believe semantic priming depends upon the prime activating items in the semantic network. If so, an auditory task might reduce facilitation either because it too draws upon the semantic network (e.g. story shadowing) or because it uses a shared attentional system.

Finally, a visual spatial cue appears to improve processing of a target because it draws attention to the target location (Posner & Presti, 1987). Data from patients with focal lesions suggest that this cueing effect depends upon two cortical areas. One of these is posterior and unique to vision (area 7) (see posterior attention, Fig. 1) and the other anterior is involved in both visual space and language processing (Posner & Inhoff, 1987). Our best candidate for the anterior area is the anterior cingulate described above. The reasons are twofold. First, we know that patients and normals who are processing language information show a reduced visual spatial cueing effect. Second, the only attentional area we have found in PET studies of word processing is in the anterior cingulate (Petersen, et al, 1988). It is known from studies of monkey anatomy that the anterior cingulate is one of many areas receiving input from both the posterior parietal lobe and the lateral prefrontal area (Goldman-Rakic, 1988). These two information sources are interdigitated within the anterior cingulate.

Thus we assume that the anterior cingulate is at least a part of the interaction between visual spatial and language attention.

How should these anatomical data influence cognitive models of divided attention? Suppose we subsume both cognitive criteria listed in our first paragraph under the common anatomical principle. Two mental operations will interfere when they require the same or highly connected anatomical areas. Thus all tasks that require attention will interfere because attention is a system of anatomically interconnected areas. For visual space this involves both the parietal lobe and anterior cingulate (among known areas) while for language it involves the anterior cingulate. The predictions for physical priming of identical stimuli are straightforward. The operations involved in visual priming should not be affected by auditory shadowing as visual priming involves only the visual word form system and auditory shadowing involves the more anterior region surrounded by dotted lines in Figure 1.

The predictions for semantic priming are much more complex. Potentially semantic priming and auditory shadowing have in common both the left inferior frontal area and the midline attentional area. However, there is evidence in cognition that a portion of semantic priming can occur without attention (e.g. Neely, 1977). Thus it is possible that semantic priming will not always use the attentional system required for shadowing. Second, shadowing may be isolated from semantics under some circumstances. A clear case for such isolation ought to be the repetition of nonsense words. PET data show little evidence of activation of the semantic area even when meaningful words are repeated (Petersen, et al, 1988).

In this paper we attempt to illustrate this joint anatomical-cognitive approach to understanding interference between tasks. The first section of the paper deals with visual priming under a variety of conditions. The second section deals with attentional cueing and the final section with semantic priming.

Visual Priming

Prototype Experiment

Visual and semantic priming stimuli were run within mixed blocks. The method for a prototype priming study (Experiment 1 in Table 6) is presented below. Variations in priming and shadowing stimuli were introduced throughout and will be addressed as they are encountered. Subjects were always native English speakers and were recruited from advertisements in local papers.

Method

Stimuli: Word list stimuli for Experiment 1 consisted of semantic, identity, unrelated and nonword pairs. Semantic pairs included: 20 good-instance category pairs (e.g. insect - fly); 20 poor-instance category pairs (e.g. ship - ferry); 20 highly associated pairs (e.g. salt - pepper) and 20 less highly associated pairs (e.g. wish - hope). The good and poor instance category pairs were selected on the basis of the Battig and Montague (1969) norms for instance dominance. Good instance targets had a mean category dominance rating of 365.8, as compared to 12.6 for the poor instance targets ($p < .001$). High and lower association pairs were obtained from established association norms (Palermo & Jenkins, 1964). High association pairs had a mean rating of 505.4 while the mean rating for the low association pairs was 98.6 ($p < .001$). Although frequency of occurrence (Kucera & Francis, 1967) was not significantly different across association pairs, high dominance targets had a significantly higher mean frequency than low dominance pairs. There were 40 identity pairs (e.g. train - train), 80 unrelated pairs (e.g. function - lace) and 200 nonword pairs (e.g. route - vorpre). In order to ensure that the effects of prime type would not be attributable to differences in frequency, unrelated pairs were constructed so as to contain the same target words as the categorical and associate pairs. Primes for the unrelated pairs did not differ in frequency from those for the semantically related pairs. Nonword and identity primes were also selected so as not to differ in frequency from those in the unrelated pairs.

In order to meet requirements for disk space, the 400 pair stimulus list was divided into two parts. One half of the items in each pair type were randomly assigned to each list.

The auditory tape used in the shadowing conditions was a reading by Gore Vidal of his novel Abraham Lincoln.

Procedure: Subjects received both word lists first in a no-shadowing and then in a shadowing condition. Each list was presented in a different random order for every subject. List order was counterbalanced such that one half the subjects received each list first.

Target stimuli were presented either a short or a long interval after the onset of the prime (SOA). SOA was randomly assigned to each item at every presentation. Prime stimuli were always initiated 500 msec after the onset of a fixation cross and remained on the screen for 300 msec. Target stimuli were initiated 400 msec after the onset of the prime in the short SOA condition and 900 msec after the onset of the prime in the long SOA condition. The fixation cross remained present throughout the duration of each trial. Primes appeared above and targets below the cross.

Subjects were instructed to fixate on the central cross and to attend to the second stimulus in each trial. Their task was to determine whether that letter string was or was not a real English word. If the target was a real word, the correct response was to press the left key on the response panel with the index of the right hand (or the middle finger of the left hand). Nonword responses were registered by pressing the right key with the middle (index) finger of the same (dominant) hand. Subsequent trials were automatically triggered through the response key.

The shadowing task involved repetition of the auditory tape, allowing for minimal lag between the tape and the subject. Subjects practiced shadowing until they felt comfortable with the task. They were then instructed to again perform the lexical decision task while maintaining the speed and accuracy of their shadowing. No formal measure of shadowing performance was obtained.

Response accuracy and reaction times for the lexical decision task were stored by computer for later analysis.

Results

In this section we consider the results for visual primes and unrelated words from Experiment 1 and the subsequent priming studies. In section 3 we will consider the data obtained for various forms of semantic relationship.

Table 1 shows the means of the median RTs for the visually primed targets and targets following unrelated words when the lexical decision task is performed by itself (focal) and when it is time shared with shadowing the Lincoln story (divided). An analysis of variance of these values shows a significant priming effect, $F(1,11)=6.2$, $p<.02$ and no significant effect of the shadowing on the amount of visual priming, $F=1.08$.

INSERT TABLE 1

Extension Experiments

We have now run the visual priming condition as a part of six classification experiments (see Table 6 for a summary of the different tasks). It has frequently been noted that lexical decision tasks often allow the presence of a relationship between prime and target words to confound the lexicality judgment (Neely, Keele & Ross, 1986). This confound arises when the presence of such a relationship means that the target string must be a word. This type of confound might be particularly important for visual identity priming where the prime-target relation is especially obvious.

We used two different techniques (Experiments 3 and 6) to reduce the use of this type of strategy in our studies. In Experiment 3 we added identical non-word pairs, thus precluding classifications based solely on a physical match. The amount of visual priming in this study is displayed in Table 2 (columns 2 and 3) for both word and non-word pairs. These data can be compared with column 1 which represents a straight replication of the prototype experiment with its confounding of relatedness and lexicality. It is clear that the visual priming is the same in the replication experiment as in the original and the new condition also gives essentially the same results.

Inspection of Table 2 also reveals that visual priming of non-words failed to produce significant facilitation in either the focal or divided conditions. Nonword visual matches, however, were only half as frequent as word visual matches. Although there are several possible explanations for the absence of visual nonword priming, the result further supports the idea that visual priming is somehow related to the lexicality of the target string and cannot be explained through a matching strategy.

A second way to eliminate the confound between relatedness and classification is to change from a lexical decision task to a semantic classification task. In Experiment 6 subjects were required to classify animal names into the categories 'predatory' or 'non-predatory'. The same related prime could thus occur for targets in both categories. As can be seen in column 4 of Table 2, the degree of physical priming was not reduced in this task.

INSERT TABLE 2

Type of Shadowing

We examined two forms of shadowing in order to establish the generality of the results obtained so far. The experiments were similar to our prototype experiment except that the subject either did the visual task alone, shadowed a story, or a list of nonsense words. The basic idea was to vary the degree of semantic content of the shadowed message. In Table 3 we look at the amount of improvement from priming as a function of the type of shadowing. The story shadowing data is the mean of three experiments (Expts. 1, 2 & 3) and is compared with the nonsense shadowing values from Experiment 3. There is no effect of type of shadowing on the amount of visual priming.

INSERT TABLE 3

Discussion

It is clear that the facilitation due to visual priming is not reduced by performance of a secondary shadowing task. Significant visual priming was obtained over a range of primary and secondary task conditions. In particular, two lines of evidence suggest that visual priming does not depend upon the strategic use of a prime-target relation to indicate a "word" response. First, visual priming was not reduced by the addition (Experiment 3) of non-word pairs with an identity relation. Second, visual priming remained intact when the prime-target relation was rendered completely orthogonal to the required judgment (semantic classification task - Experiment 6). It thus seems that the prime itself must somehow affect the classification made to the target. One possible mechanism for this might involve an implicit classification of the prime. In cases of a prime-target match, the already selected response would simply be executed. This strategy, however, should apply equally to word and non-word targets and the nonword identity pairs in Experiment 3 (table 2) did not result in priming. The means by which a prime facilitates target classification thus remains unsolved.

As a whole these findings suggest that visual priming occurs as a result of activating a pathway in the ventral occipital lobe which is then reactivated more quickly when the target occurs (see Fig. 1). If the prime effect was mediated by semantics, one would expect to find clear interference from story condition of the divided attention task (see page). It also seems unlikely that the prime effect could be based on the phonological code of the word name, as PET results suggest this code is not activated unless the subject follows a very deliberate strategy that would not be available under dual task conditions (Posner, Petersen, Fox & Raichle, in press). Moreover, mediation of visual priming via a phonological route would surely be affected by the dual task. While visual primes could have their influence on any level, the combined anatomical-cognitive approach suggest that they operate specifically on the visual representation.

We thus conclude that activating the visual code is not affected by the dual task. Can we go a step further and conclude that the visual code activation is automatic? One could argue that visual code formation involves a kind of attention not used for auditory shadowing. The most likely candidate would be the visual spatial attention system located in the parietal lobe known to be important in some forms of feature integration. However, we can reject this possibility on several grounds. First, PET studies (Petersen, et al, 1988) show that the visual code is activated passively even when the subject is instructed not to attend to it. There is no evidence of activation in the parietal lobe under these conditions. Second, patients with lesions of the right parietal lobe who neglect the left side of many objects, including letter strings, show little or no loss for reading visual words, even when they occupy the same visual angle as the letter string (Sieroff, Pollatsek & Posner, 1988).

Third, normal subjects cued to the right side of a letter string show a marked increase in errors when report the first two letters, much like the right parietal patients, but they do not have this problem with words (Sieroff & Posner, 1988). These findings show that reading a single foveally-centered word activates the visual code without automatically using the visual attention system. Thus for both cueing and divided attention methods, we find true automaticity of visual code activation under the conditions of the present experiment. Our findings support the notion that mental operations will produce no interference when they use anatomically distinct neural systems.

Visual Spatial Attention

The cognitive processes underlying visual identity priming are relatively simple, requiring only the activation of lexical codes. It is possible that it is the simplicity of the task rather than the anatomy that allows for time sharing with shadowing. It was thus important to look for interference from the auditory shadowing task on an equally simple primary task previously shown to activate the attentional system.

One such task involves shifting attention to a cued location (Posner & Presti, 1987). We use a visual cue to draw the subject's attention to a particular spatial location. If the target occurs at that location response times will be faster than if it occurs at another location. Just as a comparison between identical and unrelated primes provides a measure of priming the visual code, so the difference between response times to cued and uncued locations provides a measure of the efficiency of a covert shift of attention to the cue.

Studies of patients with focal lesions suggest that the covert shifts of visual spatial attention brought about by visual cueing are performed by activations of the posterior parietal lobe (see Figure 1). PET studies confirm the importance of this area in attending to visual locations (Petersen, Fox, Miezin & Raichle, 1988). Unlike the ventral areas involved in visual word forms, the parietal area is part of a more general attention system, with both anterior and posterior components, that is also involved in attending to language (Posner, in press). We would expect that the shadowing task would involve the anterior attentional components of this system and thus produce interference with the covert shift of attention to the cue.

Previously in connection with studies of schizophrenia (Posner, Early, Reiman, Pardo & Dhawan, in press), we ran a control condition in which normal subjects performed a visual spatial attention task either alone or together with shadowing the Lincoln story. Because the previous experiment is reported only very briefly and for such a different purpose, we briefly describe the method and results below.

Method

In this experiment twenty normal subjects were run in three blocks of covert spatial orienting (see Posner & Presti, 1987 for a full description of the task). On each trial the subject was to respond as quickly as possible to a one degree target that occurred within one of two boxes located five degrees to the left or right of a fixation cross. We will consider two types of trials, valid and invalid. Within each block, there were 96 valid trials in which the target occurred within the cued box and 24 invalid trials in which the target occurred within the box on the opposite side of the cue. On the first and third block of spatial orienting trials the subjects shadowed the Lincoln story as described in Experiment 1. On the second block they performed the spatial orienting task alone.

Results

The results for a 100 and 800 msec cue to target intervals are shown in Table 4. We examined the 100 msec interval separately because this cue to target interval is too short for any eye movements. An ANOVA of the data shown in Table 4 produces a significant effect of attention condition (focal vs. divided), $F\ (1,19) = 26$, $p < .001$; cue condition (valid vs. invalid) $F\ (1,19) = 86$, $p < .001$ and an attention by cue by visual field interaction $F\ (1,19) = 5.5$, $p < .03$. The interaction with visual field indicates that there is no validity effect (advantage of valid over invalid RTs) for left visual field targets in the divided attention condition. The interaction with visual field is not present in the 800 msec cue to target interval data.

Discussion

Two features of these data are of interest. First, unlike visual priming, we find clear interference from auditory shadowing on the effectiveness of the cue. The advantage of validly cued targets over invalid ones is 42 millisec in the focal condition and 22 millisec in the divided condition. Second, there is a strong laterality effect. When a cue is in the right visual field (left hemisphere), followed by a target in the left visual field (right hemisphere), the shadowing task produces less interference than in any other condition. We believe that right visual field cues fail to attract attention when shadowing and thus produce a reduced validity effect in the divided attention conditions.

The data show that shadowing affects the orienting of visual spatial attention even though the posterior parietal area responsible for this form of attention has been shown not to be activated by repetition of single words. We believe that this interference occurs because the auditory shadowing task ties up the anterior attentional system (see Figure 1) which, as shown previously, controls the posterior visual spatial orienting system (Posner, Inhoff, Friedrich & Cohen, 1987). Performance of the secondary task delays the command signal from the anterior to the posterior attention system and thus slows orienting to the cue. In agreement with the idea of a delayed command signal, we find that longer cue to target intervals (800 millisec), equalize the validity effects for focal and divided attention conditions.

The powerful difference between shadowing effects on cues to the right and left hemisphere has not been previously reported. Apparently the divided attention condition delays the ability of cues to fully engage attention only when they occur in RVF (go directly to the left hemisphere). For this reason, invalid targets in the left visual field do not suffer as greatly from the secondary task as the other three conditions. This finding represents the first clear evidence that the anterior attention system is lateralized in organization. The remarkable specificity of the interference produced by shadowing to the operations of one side of the anterior attention system is persuasive evidence that divided attention is not a general phenomenon but extremely sensitive to the exact details of the anatomical interconnections. Thus a very simple mental operation in the ventral occipital lobe shows no interference from the shadowing task (exp. 1), while an equally simple cueing operation within the attention system shows dramatic interference in just one half of the visual field.

Semantic Priming

Visual and semantic priming stimuli were run in mixed blocks as described for the prototype experiment. The RT for various semantic relationships and unrelated primes are shown in Table 5. Two facts are clear from the table and are confirmed by statistical analysis. The related trials are faster than unrelated trials (mean 48 msec). ANOVA shows a significant relatedness effect $F(1,11) = 5.4$, $p < .05$). The effect of relatedness is longest for highly associated pairs, next for low association pairs and is lacking for poor members of primed categories. Both the size and systematic nature of these activations suggest that priming occurred in the focal condition. The large percentage of semantically and physically related pairs was probably sufficiently salient to encourage the conscious or unconscious use of same type of strategy in lexical decision. One such strategy, which often produces large priming effects, is the active prediction of the target on the basis of the prime. In accordance with this possibility, we obtain a large reduction of the priming effect in the divided attention condition. There is no significant priming under divided attention conditions except for the high association pairs. The interaction between attention condition and semantic priming is significant $F(1,11) = 8.7$, $p < .02$. Thus shadowing tends to reduce or abolish semantic priming while not reducing visual priming under identical circumstances within the same experiment (see Table 1). The error rates in this study are small but they tend to follow the pattern of the reaction time data.

INSERT TABLE 5

The six experiments displayed in Table 6 all yielded significant visual priming of words. Significant semantic priming was obtained in all five lexical decision tasks but not in the one semantic classification task. In three of the experiments, the priming effect was reduced by some form of divided attention. This was significant in two studies. In two other lexical decision studies, there was a significant priming effect (although small) that was not affected by shadowing (see Table 7).

INSERT TABLES 6,7

Our studies were not designed to determine the exact factors responsible for the extent of semantic priming. As indicated by a vast and complex literature, semantic priming is influenced by a number of strategic factors that include percentage of related primes, interval between prime and target, backward association between target and prime, and many others. These factors were not controlled in our experiments and appear to be responsible for the variability of semantic priming in our data. Despite this, significant priming was obtained for all focal tasks except semantic classification. This may be due to the greater difficulty of this particular semantic classification task or to its success in eliminating the presence or absence of a prime-target relationship as a strategic factor.

The shift from lexical decision to semantic classification did not, however, reduce visual priming. Moreover, semantic priming during lexical decision was not greatly influenced by the percentage or type of visual identity pairs in the stimulus list. The presence of nonword identity primes, intended to reduce the confound between the presence of a prime-target relationship and a "word" decision, also failed to eliminate semantic priming.

Usually the factors that influence semantic priming are said to be of two types, automatic and strategic (Posner & Snyder, 1975). The larger priming effects of Exp. 1 and 2 may reflect greater use of strategic factors. Shadowing reduced semantic priming significantly in both studies. In contrast, both priming and divided attention had smaller effects in Exp. 3-5. We conclude that divided attention can reduce semantic priming. However, there may be a component of the priming that is unaffected by the divided attention task and thus could be said to be automatic.

If we examine Exp. 3, 4 & 5 where different forms of shadowing were used, we see that nonsense shadowing has as large or larger an affect on the priming task as story shadowing. This suggests that it is not the semantic character of the secondary task, but rather its use of attention that influences the degree of semantic priming. We know from PET data that repeating meaningful words activates the anterior attention system, but we have no evidence that it affects the left lateralized semantic system. Thus we cannot be sure that story shadowing actually has an effect on the semantic area. Subjects were, however, aware of the meaning of the text and able to answer questions about it asked after the experiments.

In short, semantic priming is like visual spatial attention and unlike visual priming in involving the attention system. We expect there may be a component of semantic priming that is automatic and is not affected by shadowing, but we have not yet demonstrated that clearly.

Conclusion

We have attempted in this paper to lay out a combined cognitive and anatomical approach to aspects of visual word recognition. We used cognitive techniques (priming) to obtain pure measures of visual activation, visual attention and semantic activation. We have shown that the visual activation component is simply not influenced by a difficult divided attention task that is perfectly adequate to provide interference with overall reaction time, visual spatial orienting and aspects of semantics. This seems to be strong confirmation that the visual word form activation is "automatic". First, we have shown elsewhere that it is automatic in the sense that it is unaffected by lesions or activation of the posterior attention system (Sieroff, et al, 1988a,b). Second, we have shown that it is automatic in the sense that the degree of blood flow in this system is not affected by the subject's passive versus active task state (Petersen, et al, 1988). Third, in this paper we show that it is automatic in that it perfectly time shares with the divided attention task. These findings support the assumption that an operation that occurs automatically in an area of the brain not used by the secondary task will show no interference. These data indicate that visual word forms can be computed even though the person is engaged in other activity and are compatible with many findings in the reading literature (Rayner & Pollatsek, 1987).

In contrast to the results for visual priming, visual attention is greatly affected by simultaneous shadowing. This occurs despite the fact that cueing appears on the surface to be just as simple as visual priming and clearly involves no language. The clear interference of shadowing on the speed of visual orienting is remarkable evidence in favor of a unified attention system which in different anatomical areas involves visual spatial (posterior) and language (anterior) information. The interaction betwen the two support the anatomical (Goldman-Rakic, 1988) and cognitive (Posner, Inhoff, et al, 1987) evidence that the anterior system relates prefrontal (semantic) and parietal (visual spatial) information. Moreover, the lateralized affects of shadowing on visual cueing suggest that the anterior attention system is lateralized. It is consistent with the idea that the left anterior cingulate provides information to the left parietal lobe needed to engage attention to a cue in the right visual field.

One of the most remarkable aspects of these data is the clear separation between semantic and visual priming. Although the two prime types were mixed within the same block and task, they produced quite different patterns of facilitation. This cognitive result is compatible with several lines of anatomical evidence that visual word forms and semantic information are processed in separate areas. First, as discussed previously, our PET results (Petersen, et al, 1988) show visual word forms to activate an occipital region and semantic processing to activate a region in the frontal lobe. Second, event-related potential data (Rugg, 1987) show a posterior distribution for visual priming and an anterior distribution for semantic priming.

From a cognitive perspective, anatomical separation of initial visual word form and semantic computations does not necessarily imply that visual and semantic priming occur in those same regions. Afterall, a visual identity prime also has a semantic identity. The role of semantic analysis in lexical decision, both whether it occurs at all and if it does at what stage in processing, remains controversial. While the use of pronounceable nonwords has been shown to encourage semantic analysis (James, 1975), it remains possible that other information is important in semantic priming. Our data, however, strongly suggest that the two forms of priming have a separate anatomical as well as a separate functional basis. This result augers well for the use of these two forms of priming as a tool for assaying the relative intactness of the ventral occipital lobe and prefrontal cortex in patients with various psychiatric and neurological disorders.

Our results for semantic priming are not as definitive as for visual priming although we see no reason that they cannot be made so through better control of priming techniques. Our results do show clearly that semantic priming can be affected by a secondary auditory shadowing task. Since the PET data do not show that repetition of meaningful single words activates the semantic area, the two tasks may share only the anterior attentional system. The present data show only that semantic priming is reduced by shadowing under some conditions and suggest that the reduction is, as the PET data would predict, mediated by the shared attention system. This last point is supported by the finding that shadowing a meaningful story produced no greater interference on a lexical decision task than shadowing nonsense.

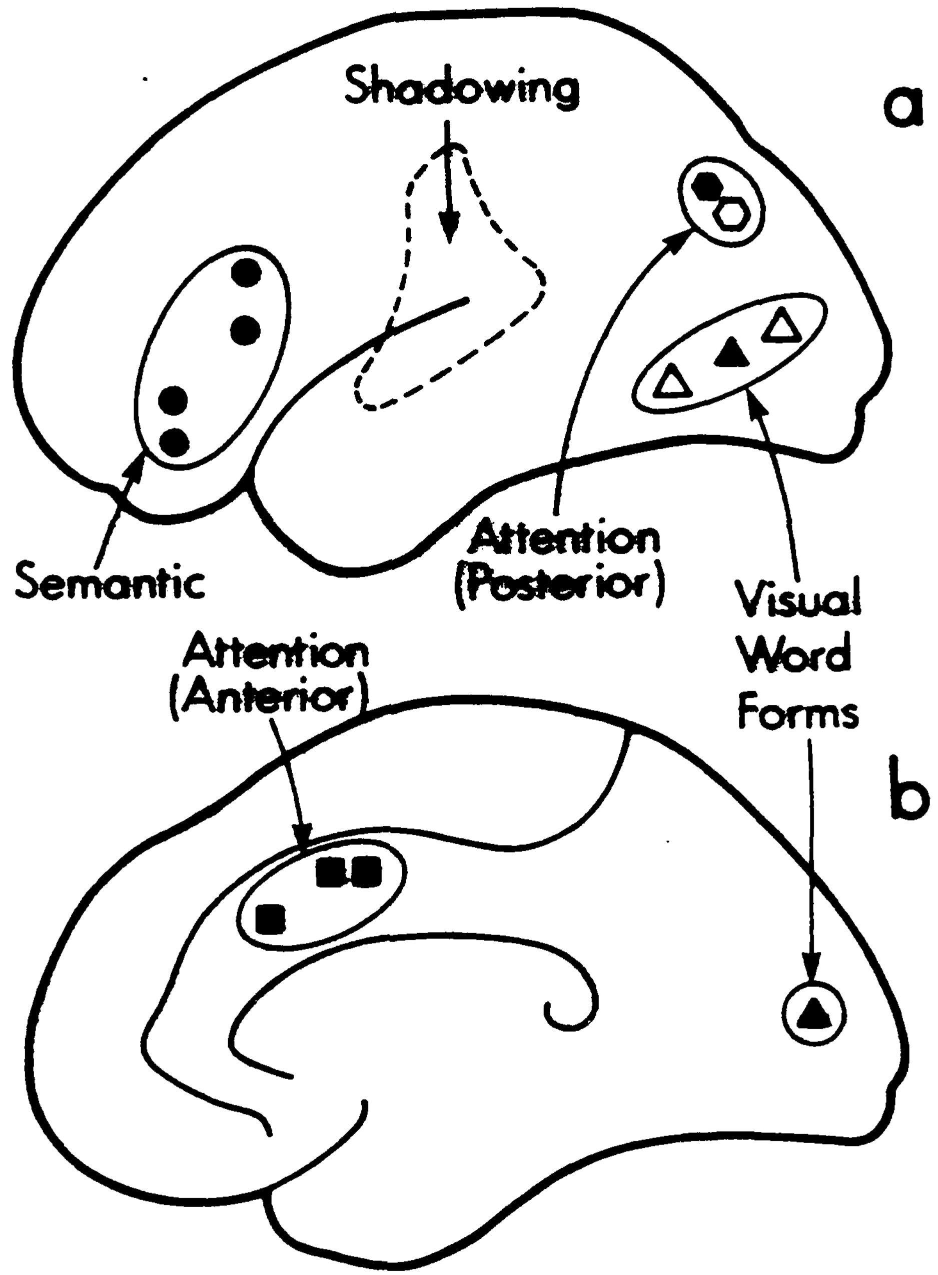
There does appear to be a portion of the semantic priming effect that is immune to attentional interference (Experiments 5 and 6). The cognitive literature suggests that this portion may reflect the automatic activation often reported after very short prime-target intervals. A number of tasks are available to pursue the issue of automatic activation. Moreover, the PET data suggest auditory tasks that involve semantic classification do activate the semantic area. The study of the relationship between the non-attentional components of semantic priming and the anterior semantic system through interference in a dual task paradigm remains a promising area for future research.

The study advances our goal of developing joint constraints from cognitive and anatomical studies. The operation of the ventral occipital lobe in obtaining the visual word form appears to be automatic. However, this is clearly not the case for all operations performed in this area. While single foveally-centered words can be reported by parietal patients, they have great difficulty in visual search and nonword reports. Thus the operations that take place within a given area can be either automatic or attended. The use of cueing and divided attention techniques can clarify this issue.

The close relationship between the anterior attention system and the semantic system (see Fig. 1) seems to us to be of particular importance. We have argued elsewhere that difficulties in the anterior attention system can lead to bizarre abnormalities in thought and language found in schizophrenia (Early, Posner & Reiman, submitted). A closer look at the types of operations that can be computated automatically within this system and those that require attention may be fundamental to an understanding of higher level disturbances of cognition.

Figure Caption

A summary of data from PET studies of visual and auditory words (Petersen, et al, 1988). The areas on the lateral portions of the cortex (a) and on the medial portion (b) that are involved in visual word forms (triangles), semantic analysis (circles), anterior attention (squares), or posterior attention (hexagons). For lateralized activation solid indicates left hemisphere and open indicates right hemisphere. The hemisphere of midline activations is not known. The areas thought to be activated by repeating auditory words (shadowing) are surrounded by a dotted area.



Shadowing
a
Semantic
Attention
(Posterior)
Visual
Word
Forms
Attention
(Anterior)
b

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Table 1

Mean Reaction Times (msec) for Identity and Unrelated Pairs

	Identity	Unrelated	Priming Unrelated-Identity
Focal	641	693	52
Divided	667	738	71

Table 2

Amount of visual priming (msec) as a function of type of task and the presence of nonword primes.

	Identity			
	Lexical Decision			Semantic Class
	words only (Exp. 2)	words mixed (Exp. 3)	nonwords mixed (Exp. 3)	words only (Exp. 6)
Focal	54	54	7	87
Divided	84	81	20	76

Table 3

Visual priming (msec) as a function of the type of secondary task

No Task	Shadow Story	Shadow Nonsense
62	80	65

Table 4

Mean RT (msec) as a function of cue and attention conditions

	Valid Trials		Invalid Trials		Validity Effect Invalid-Valid
	Visual Field of Target				
	100 millisec*				
	Left	Right	Left	Right	
Focus	353	349	397	391	42
Divided	452	441	459	479	22
Increased RT from Dual Task	99	92	62	88	
	800 millisec*				
Focus	304	304	334	333	30
Divided	401	409	430	438	29
Increased RT from Dual Task	97	105	96	105	

* Cue to Target Interval

Table 5

Mean of the median RTs in millisec for targets following various types of primes for focal and divided attention conditions

	High Assoc.	Low Assoc.	Good Instance	Poor Instance	Unrelated
Focal	608	628	653	691	693
Divided	690	712	745	773	738

Table 6

Survey of Prime Conditions in Six Priming Experiments

Exp.	Task	#Ss	Intervals	Total Trials	% Rel Primes	# Visual Primes	Semantic Primes	Unrelated Primes
1	Lex. Dec.	12	100	400	30	40	80	80
			600					
2	Lex. Dec.	24	100	480	25	40	80	120
			600					
3	Lex. Dec.	12	100	240	31	30*	30	30
			600					
4	Lex. Dec.	12	300	180	17		30	30
5	Lex. Dec.	12	300	240	25	30	30	30
6	Semantic Class.	11	100	142	50	24	46	72
			600					

* In addition, there were 16 nonword visual identity primes and 14 nonword primes that were not visually identical.

Table 7

Amount of semantic priming (msec) in six experiments for focal and divided attention conditions.

Exp.	Task	Attention Condition		
		Focal	Shadow Story	Shadow Nonsense
1.		48*	6***	
2.		39*	13	
3.		20**	21	-6***
4.		23*	13	26
5.		17*	19	22
6.		19	13	

* Signifies a significant semantic priming effect in the focal condition

** Significant interaction between priming and attention condition

*** Signifies a significant reduction in the amount of priming under the specified divided attention condition

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